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16. ABSTRACT

Primary Purpose

The speed of construction work has been steadily increasing for many years. The size of contractor units and the amount of hauling equipment means that materials for bases, subbases and for bituminous surfaces are being produced and moved to the road at a tremendous rate compared to earlier years. Most gravel pits or quarry sites contain varying amounts of fine materials which may also vary in type from fine sand to clay and very often these materials are not uniformly distributed. An excess of clay is usually detrimental to the performance of any aggregate whether for gravel base, bituminous mixture or Portland cement concrete. It is, therefore, important that the engineer be in a position to quickly detect the presence of undesirable quantities of adverse clay-like materials and the need has long existed for some quick method of test which could be employed in the field by the engineer or inspector in charge of construction.

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Sand Equivalent Test

State of California
Department of Public Works
Division of Highways
MATERIALS AND RESEARCH DEPARTMENT
Sacramento, California

June 23, 1952

General Information FNH/4

Subject: Sand Equivalent Test

To the District Engineers
of the Division of Highways

The Sand Equivalent Test, to control the quality of aggregates for bituminous mix and untreated bases, is being proposed for inclusion in our revised Standard Specifications and is currently appearing in the Special Provisions for many contracts.

It appears that a more detailed explanation of the scope and significance of this test is now in order.

Primary Purpose

The speed of construction work has been steadily increasing for many years. The size of contractors units and the amount of hauling equipment means that materials for bases, subbases and for bituminous surfaces are being produced and moved to the road at a tremendous rate compared to earlier years. Most gravel pits or quarry sites contain varying amounts of fine materials which may also vary in type from fine sand to clay and very often these materials are not uniformly distributed. An excess of clay is usually detrimental to the performance of any aggregate whether for gravel base, bituminous mixture or Portland cement concrete. It is, therefore, important that the engineer be in a position to quickly detect the presence of undesirable quantities of adverse clay-like materials and the need has long existed for some quick method of test which could be employed in the field by the engineer or inspector in charge of construction.

Basic Factors

All pavements, bases, subbases and the underlying basement soils have one thing in common. All are composed of rock fragments which range in size from colloidal particles less than one micron in diameter up through the sand sizes to and including coarse stone. Basically, these materials derive from the fracturing and breaking up of various types of stone; therefore, we are concerned with the properties and mass relationships of rock particles. Within rather narrow limits there is not much difference in the capacity of uncemented granular materials to sustain loads. In other words, while there are differences between clean sands, gravel or crushed stone, all of these materials have been found adequate for constructing bases or subbases for highway pavements, and sand, gravel or crushed stone particles are used in combination with cementing agents such as asphalt or Portland cement to form pavements. It is also true that granular materials may be "cemented together" by natural binders such as clay or rock dust.

It is a matter of common knowledge among highway engineers that an excessive amount of asphalt in an otherwise normal mixture of sand and gravel will cause instability because the asphalt is a lubricant and provides mobility or plasticity to the mass. The same observation can be made concerning the effects of clay. It may be noted, however, that when compared on the basis of weight, less asphalt will be required to produce instability than is the case with clay. For example, a dense graded aggregate will usually be unstable with 7% of asphalt by weight while over 10% of plastic clay soil might be required to produce the same effect. This difference exists, however, only in the weight relationships as the volume of asphalt corresponding to 7% of the dry weight of the aggregate is about equal to the bulk volume of wet clay corresponding to 11% by weight of the total aggregate. It should then be apparent that lubrication does not become serious until a certain volume of lubricant has been introduced, and, to carry the analogy further, if the aggregate were mixed with a plastic material such as red lead paint, instability would also be produced but in this case it would require approximately 23% by weight although the volume relationships would still remain about the same. It should not be necessary to dwell upon this relationship unduly but the conclusion is inescapable that the fundamental relationship in all design of aggregate mixtures whether for concrete, bituminous pavements, or gravel bases rests upon the relative volumes of each ingredient and not upon weight percentages. This fact is often overlooked.

The control of bituminous mixtures is simplified by the fact that paving asphalts do not vary widely in specific gravity but the clay minerals do vary in weight, and to illustrate the wide range of volume which can exist with the same weight of dry material, Figure 1 is included wherein a series of glass graduates are shown, each containing 100 grams of dry mineral powder or rock dust of the types often referred to as "filler dust" when used in asphaltic mixtures. It should be readily apparent to any engineer that a sieve analysis of mineral aggregates expressed as the weight percentages of each size does not necessarily give a true picture of the relative volume or mass of material represented by the size groups. As a further illustration, Figure 2 shows a series of mineral aggregates of much coarser gradation, each representing an aggregate of different specific gravity and again illustrating that the total volume of material represented by a pound or a ton may vary widely. However there are still more variables and it is even more important to realize that while it is troublesome to maintain proper proportions between aggregates and binders that vary in unit weight, the problem becomes more complex when the mineral aggregates consist of several types of stone particles each having a different specific gravity. Figure 3 illustrates some of the contrast which may occur between mineral aggregates which are made up of identical gradations when expressed by weight but it will be observed that the volume proportions are vastly different. Troublesome as these variations can be it is nevertheless possible to determine the specific gravity of each size group and by calculation arrive at the true volume relationship. This is routine procedure in concrete mix design, but is usually overlooked in other cases.

However, there is another factor involved when water is introduced into soils or untreated base materials. In these cases, certain clays may expand considerably and the effective volume of wet lubricating clay may be greatly increased or augmented. This condition is most marked in the montmorillonite class of clays of which bentonite is a well-known example. (Other clay types may expand but to a lesser degree). In any event, an estimate of the amount of clay may be very misleading when based upon sieve analysis, hydrometer analysis, or upon any other means which leads to an expression in terms of weight percentages.

Figure 4 shows two graduates, each containing an amount of sand and clay which, when thoroughly mixed with water, produced an R-value of 60. (Without the clay this sand has an R-value of 80). It will be noted that the amount of sand is the same in each case but graduate (a) contains only 5% of bentonite where graduate (b) contains 21% of kaolinite by weight. In the weight proportions shown, these materials have an equal effect in reducing stability or increasing the plasticity of the entire mass and therefore bentonite is a much more effective lubricant and consequently can be far more troublesome than kaolinite for example. The wide spread use of weight batching or proportioning devices and also the use of scales or balances in laboratory analyses have tended to obscure the important relationships that depend upon relative volume.

The Sand Equivalent Method

The Sand Equivalent Procedure was developed in order to evaluate the effective volume of clay that exists in each soil. In order to permit a rapid test procedure by avoiding time consuming weighings and drying out operations, the test is performed on a sample of soil passing a #4 sieve measured by loose volume. The relationship between the quantity of clay present and the amount of coarser sand particles in the soil is developed on a volume basis and the test indicates whether the volume of "sand" in the soil is high or low - hence, the name "Sand Equivalent".

Essentially the test is performed by shaking vigorously in a transparent cylinder a sample of the fine aggregate and noting the relative volumes of sand and clay in suspension after standing for 20 minutes. The entire operation can be carried through in less than 40 minutes. In order to speed up the sedimentation of the fine clays or colloidal particles a flocculating agent was required and a solution of calcium chloride was selected on account of its relatively low cost, stability and non-irritating properties. As illustrated in Figure 4, a small amount of bentonite is in lubricating effect equal to a much greater weight of kaolinite and the strength of the $CaCl_2$ solution was adjusted to the point where 5% of bentonite would give an S.E. reading approximately equal to that produced by 25% of kaolinite after a sedimentation period of 20 minutes. This relationship appeared to be best established by using a .025N $CaCl_2$ solution. However, the strength of the solution is not critical for most natural soils therefore, a working solution of .05N has been adopted and will be used until accumulated experience may warrant a change. After some experience with the calcium chloride solution, it was found that the addition of a small amount of glycerin produced a stabilizing effect and test results were more readily reproducible when made on carefully quartered samples. Finally, it was noted that the calcium-chloride-glycerin solution was not sterile and certain moulds tended to grow. In order to sterilize the solution, formaldehyde was added.

Numerous attempts have been made in district laboratories to establish a "correlation" between results of the Sand Equivalent Test and the evaluation of a soil obtained by other test procedures. The fact that such attempts have not been completely satisfactory does not necessarily mean that the sand equivalent vales are unreliable or meaningless.

Comparison with Other Tests

Plasticity Index

The Plasticity Index or P.I. value has long been used to indicate the range in moisture content over which soils are "in a plastic state". The degree of plasticity is not indicated by the test and the material used in the standard procedure is obtained by dry sieving and collecting the material which will pass a No. 40 sieve. If colloidal clays are present, these are very likely to exist as a coating on all the coarser particles and can only be removed by washing involving a vigorous scrubbing action. The Sand Equivalent Test discloses all of the clay contained in the sample and may often indicate a more adverse condition than would be inferred from the P.I. determination.

Comparison with the C.B.R.

The fact that the C.B.R. test is known to have a poor correlation with performance of many base materials means that any disagreement with the S.E. determination is not particularly significant. For example, a clean sand of 30 C.B. R. could easily have an S.E. of 90.

Correlation with the R-Value

When the Sand Equivalent Test was first developed, it was hoped that it would furnish a good indication of the over-all resistance value of the soil. A correlation does exist but it is not sharply defined throughout the scale. The reasons therefor are not difficult to understand if it is recognized that the ability of a mass of soil or granular material passing a No. 4 sieve to resist deformation will depend upon the following factors.

Summary of Factors Affecting Resistance Value of Soil

1. The amount of lubricant mixed with the sand fraction; i.e., asphalt, clay+water, etc.

2. The effectiveness or efficiency of the lubricating fraction. (Wet bentonite is a better lubricant than kaolinite, for example.)

3. The degree of roughness or irregularity of the sand grains or rock particles.

4. The amount of void space in the sand fraction of the soil.

5. The amount of intermingled coarse rock retained on a No. 4 sieve.

We readily perceive that of these five variables the Sand Equivalent determination is primarily an indication of No. 1. It attempts to compensate for No. 2 by means of the type of solution used. It cannot indicate the variation caused by Item 3, and as presently performed does not make allowance for No. 4 although it seems possible that means for making this correction may be worked out. Allowance for the effects of No. 5 need to be made if the coarse aggregate exceeds 25 or 30 percent of the total. Therefore, in order to evaluate the combined effect of all factors some test such as the Stabilometer is necessary. However, experience has shown that one of the principal variables is the amount of clay present and it may readily be determined that when the Sand Equivalent value is greater than 30 the clay fraction is not sufficiently large to have much influence on the resistance value of an untreated soil.

Application and Tentative S.E. Limits

Bituminous Mixtures

Very small amounts of clay may be detrimental to the performance of bituminous mixtures, especially when the clay exists as a coating on the surfaces of the sand grains. As the Sand Equivalent determination furnishes a ready means for detecting the presence of such fine materials, a tentative scale of values has been set up to permit rapid testing and quick determination in the field. For the highest type of bituminous paving mixtures corresponding to asphaltic concrete, an S. E. value of 60 has been established. This requirement is readily met by the majority of commercial plants in the state even when 8% of commercial filler has been added. A value of 50 is proposed for the Type "B" Plant-Mix thus providing slightly greater tolerance.

Untreated Bases

For untreated rock bases upon which the performance of bituminous pavements are completely dependent, an S. E. value of not less than 30 is proposed.

Basement Soils

In comparing the Sand Equivalent to other test values, a heretofore unsuspected relationship was found indicating that the majority of materials showing high expansion values may be identified by means of the Sand Equivalent. Therefore, it would be possible to insure the placing of only the better material within 24" of profile grade by placing in the bottom of fills any soil having a Sand Equivalent less than 10. This would have the same effect as the present requirement - (Standard Specifications, Section 12, Chapter V, (a), last paragraph.) It has been the general practice to avoid placing in the upper 2 feet of the roadbed any material showing an expansion greater than 5%, and an S.E. value of 10 or less will identify the same general class of soils.

Concrete Aggregates

A recent examination of concrete sands indicates that a large majority of commercial concrete sands will pass a Sand Equivalent minimum of 80 or 85. There appears to be no reason why the S. E. test procedure cannot be used to control the amount of clay in fine aggregate for Portland cement concrete. The vigorous shaking action will remove ordinary clay coatings on the sand particles.

Conclusion

It cannot be too strongly emphasized that successful construction and the ultimate performance of any pavement rests completely upon the care and diligence of the resident engineer and his assistants who are in direct charge of the work. No amount of preliminary materials exploration nor of control testing in District or Headquarters Laboratories can guard against the introduction of excess amounts of clay either in the base materials or in aggregate for bituminous paving mixtures and it is essential that the resident engineer and his assistants be provided with some means of rapid determination and warning of the presence of such materials. The fact that successive tests on a deposit may indicate a range of values does not necessarily prove that the test procedure is erratic or irreproducible. It is much more likely to mean that the materials in the deposit are variable. The existence of localized or spot failures on many roads is ample evidence that this non-uniformity or variability of pit run materials is the rule rather than the exception.

It must also be recognized that complete correlation rarely exists between the results of any two different tests. If such a correlation does exist then only one of the two tests should be retained. Regardless of R-values, P.I. limitations or any other requirement, experience has shown that more trouble results from too much clay or "mud" than from any other cause and it is the purpose of the Sand Equivalent test to prevent the inclusion of undesirable amounts of clay without the knowledge of the Engineer in charge.

In order to be effective, specifications must contain requirements indicating the course of action to be followed when the materials do not comply with the specification requirements. The only remedies for this particular problem are dilution with clean granular material, production of aggregate by crushing from oversize or by washing.

A detailed description of the Sand Equivalent test procedure is available for those who expect to perform the test.

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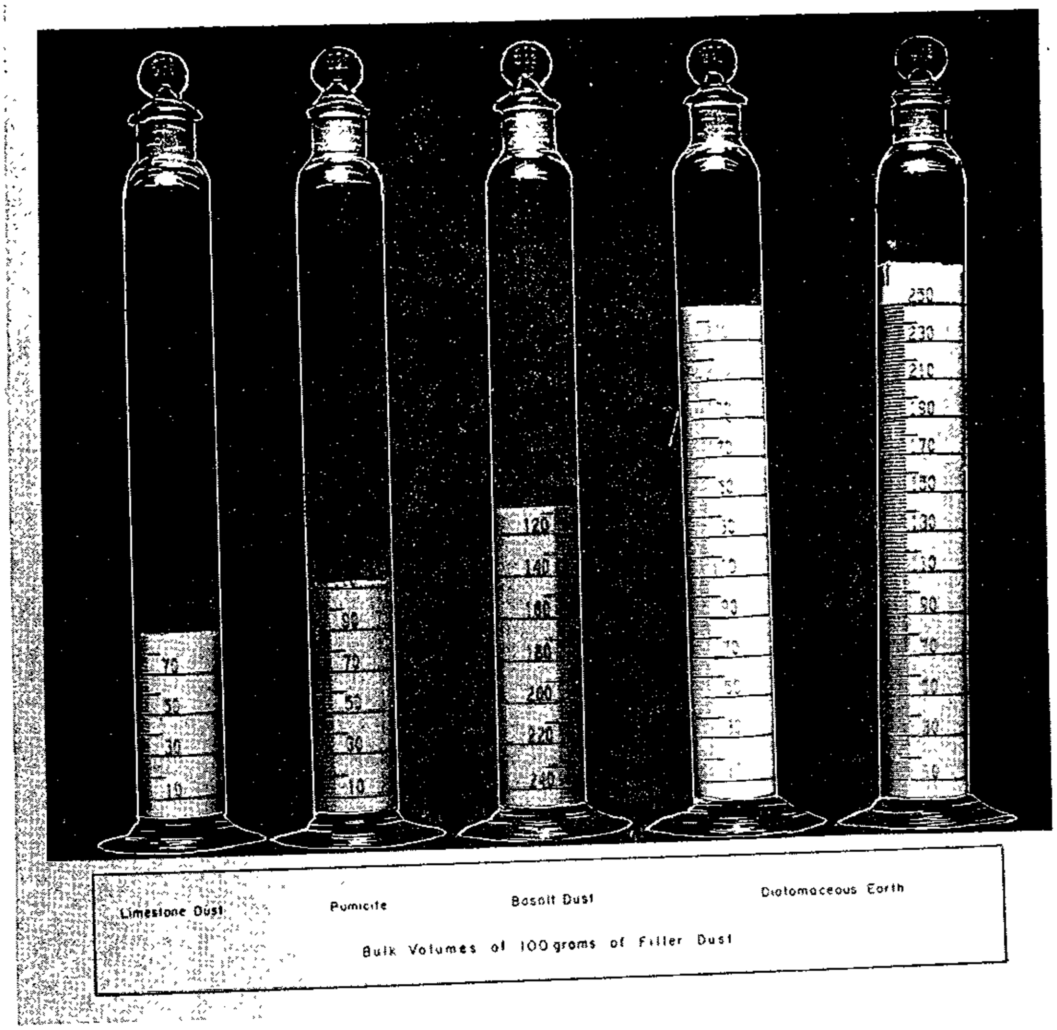
Limestone Dust
Pumicite
Basalt Dust
Diatomaceous Earth
Bulk Volumes of 100 grams of Filler Dust

Fig. #1

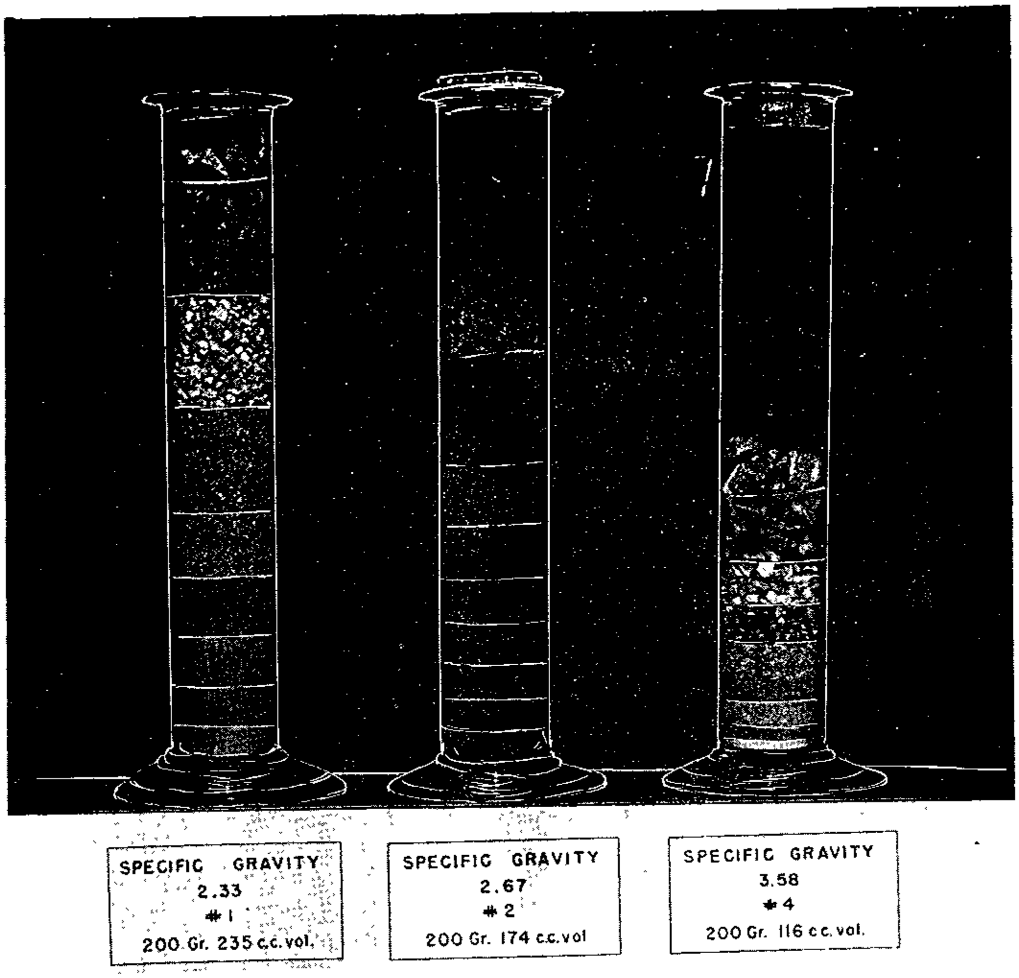
SPECIFIC GRAVITY
2.33
1
200 Gr. 235 c.c. vol.
SPECIFIC GRAVITY
2.67
2
200 Gr. 174 c.c. vol
SPECIFIC GRAVITY
3.58
4
200 Gr. 116 c.c. vol.

Fig. 12

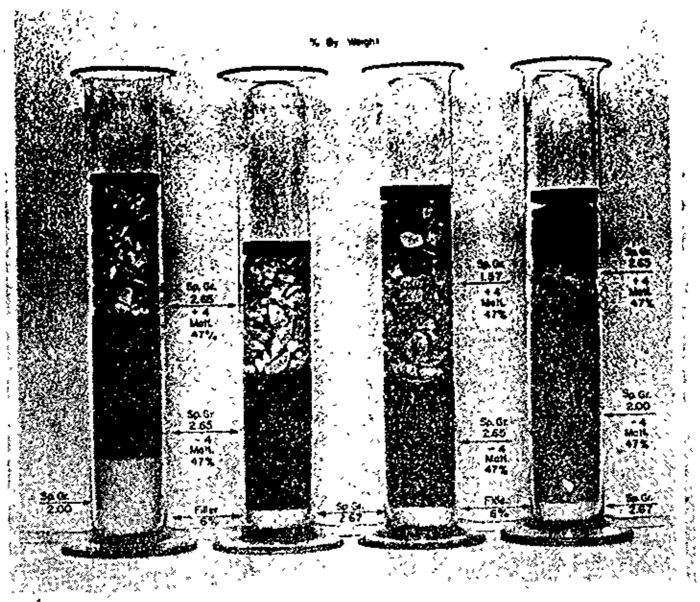
% By Weight
Sp. Gr. 2.65
+ 4 Matl. 47%
Sp. Gr. 2.65
− 4 Matl. 47%
Sp. Gr. 2.00
Filler 6%
Sp. Gr. 2.67
Sp. Gr. 1.57
+ 4 Matl. 47%
Sp. Gr. 2.65
− 4 Matl. 47%
Filler 6%
Sp. Gr. 2.65
+ 4 Matl. 47%
Sp. Gr. 2.00
− 4 Matl. 47%
Sp. Gr. 2.67

Fig. #3

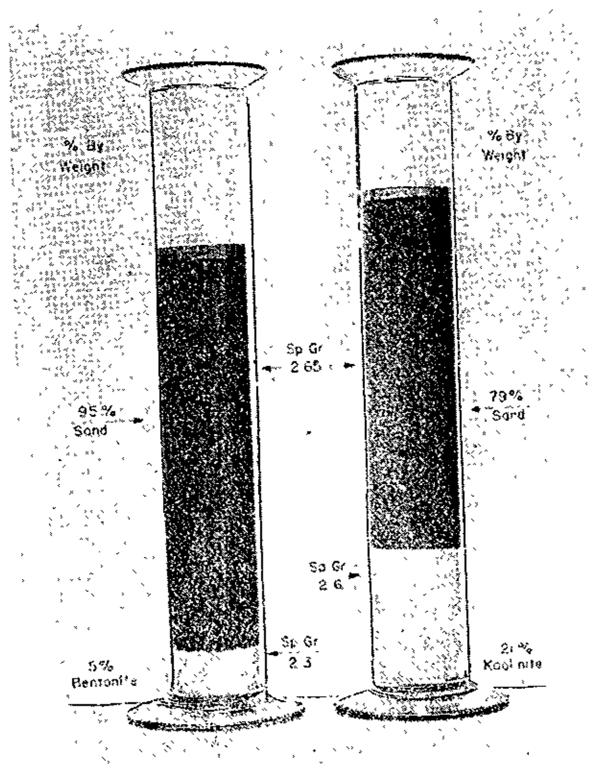
% By Weight
% By Weight
Sp Gr 2.65
95% Sand
79% Sand
Sp Gr 2.6
Sp Gr 2.3
5% Bentonite

Fig. 4.